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NATIONAL BUREAU OF STANDARDS REPORT

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ACOUSTICAL PERFORMANCE
OF
SOME FLOOR COVERINGS FOR HOSPITALS

Technical Report to

Hospital and Medical Facilities Division
Public Health Service
U. S. Department of Health, Education and Welfare

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

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ACOUSTICAL PERFORMANCE
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ABSTRACT

Relevant literature is summarized in order to describe and characterize the nature of hospital noise problems. The role played by floor coverings in the total acoustical environment is examined. Random- and normal-incidence sound absorption coefficients are presented for some floor coverings. The improvements in the impact sound insulation are presented as a function of several different floor coverings installed upon a basic concrete structural floor. In addition, the relative surface noise radiation resulting from the movement of various hospital carts over two different floor coverings in a known acoustical environment is shown. The development of acoustical performance criteria is discussed. Suggestions are made for needed additional laboratory and field studies of the hospital acoustical environment and the acoustical properties of materials and systems.

Key Words: Acoustics, floor coverings, hospitals, impact sound insulation, noise control, sound absorption, sound control

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1. Introduction

Well and healthy people can enjoy the peace and quiet of their homes. The ill and infirm, however, often are subjected to the noisy environment of hospitals. The need for relative quiet and acoustical privacy for patients requires very little explanation. Similarly, the requirements for a clean hospital, free of dust and bacteria, are also apparent. In order to satisfy the latter requirements, interior finishes of hospitals characteristically are in conflict with the principles of noise reduction through sound absorption. These finishes are highly reflective and result in the creation of reverberant spaces that tend to intensify noise problems.

In this study, merely the roles of floor-covering materials are examined as they relate to the acoustical environment in hospitals.

1.1. Objective

The overall objective of this study was to develop acoustical performance criteria for hospital floor coverings that would contribute to a reduction of noise in hospitals and allow performance specifications to be written for floor-covering materials.

1.2. Background

This study was a part of a broadly-based program that considered several aspects in the development of performance criteria for hospital floor coverings. A report, titled The Performance Concept--Its Application to Hospital Floor Coverings [1][1] has been prepared. That report contains results of investigations of performance characteristics, other than acoustical. This report complements it with the acoustical performance information.

1.3. Scope

The scope of this study involved a survey of the pertinent literature to determine the nature of the extant noise problems in hospitals. Discussions with hospital personnel and personal tours supplemented the surveyed literature. The role of floor coverings was explored. Laboratory measurements of some of the acoustical properties of several floor coverings were made to determine the range of performance achievable with commercially obtainable materials.

[1]The numbers in brackets refer to numbered bibliography entries.

2. Hospital Noise

The following information is summarized from the literature and is essential to the evaluation of the contributions of floor coverings in the hospital acoustical environment.

The publication titled Noise in Hospitals - An Acoustical Study of Noises Affecting the Patient [2] is very useful. The study was based on a survey of the noises found in modern hospitals and of the patients' responses to the noises. Among the subjective findings is a list of the "most prevalent sounds arranged in order of annoyance" as follows:

1. Radios or television sets
2. Staff talk in corridors
3. Other patients in distress and recovery room sounds
4. Voice paging
5. Talk in other rooms
6. Babies or children crying
7. Telephones
8. Pantry, kitchen, utility room

It is interesting to note that all of the sounds, with the possible exception of the last, are "airborne sounds" that could be reduced somewhat in intensity with the use of absorbent materials. Many listed sounds seem to imply their transmission from one space to another; e.g., corridor to patient's room, pantry to patient's room, patient's room to

patient's room.

Noises or noise sources bothering patients that are directly influenced by the nature of floor coverings are listed as follows:

1. Walking in corridors
2. Carts: medicine, linen, other
3. Cleaning equipment: buckets, trash containers
4. Floor polishers
5. Pans or objects dropped
6. Chairs dragged or scraped; furniture moved
7. Portable scale on wheels

The noise produced by walking in the corridors was attributed mainly to visitors, although a number of instances were observed where hospital personnel were at fault. Volunteer aides delivering flowers and the like often wore high-heeled shoes. The squeaking sounds produced by "ripple-soled" shoes were annoying especially on newly-waxed floors, even though the shoe soles were made of rubber.

The rumbling sounds resulting from wheeled carts rolled along floors are complex. In addition, there is the sound produced by the wheels in dynamic contact with the floor-surfacing material; but in addition, there are also the sounds of squeaking or loose casters, the rattling of the cart contents; and in some cases, the sounds radiated from the hollow tubular frames.

Cleaning equipment such as metal scrub buckets, trash containers and the like, can cause noises that need no further description. Similarly, the sounds of pans and other dropped objects are disturbing.

Floor polisher and vacuum cleaner motor noise usually overpowers the sounds produced by contact with the floor covering. As indicated in this report, some of the bothersome noises could be eliminated at the source or reduced in intensity through thoughtful design of the devices in question.

Another study related to the acoustical environment of hospitals is titled, Noise in Hospitals Located Near Freeways [3]. The fundamental objectives of this study were to determine changes in economic status of hospitals resulting from the introduction of an adjacent freeway and to study the noise levels produced by freeway traffic and the effect of the noise on those inside the hospital. During the course of the study, the noise environment of each of ten hospitals was measured both inside and outside; and in addition, questionnaires were distributed to patients and hospital personnel to obtain their subjective response to the noise environment. Several questions relate to the interior environment; for example, the subjects were asked to list specific noises or noise sources that they "had in mind" while

rating the frequency of occurrence of "annoying noises".

The questionnaire summary sheets of each of the ten hospitals were examined and the responses were categorized into twelve groups. Eight of the twelve categories[2] relate to the interior noise environment and are defined as follows:

Noise Category	Definition
a. Patients or Visitors	Usually conversation, but including moaning, laughing, crying, etc.
b. Hospital Personnel	Conversation by doctors, nurses, or others on the hospital staff.
c. Hospital Equipment	Trays, carts, dishes, bedpans, or any equipment generally handled by hospital personnel.
d. Signaling Devices	Buzzers, bells, telephones (ringing), except intercom.
e. Intercom	Including "canned" or piped-in music.
f. Radio or TV	Patient-controlled only.
g. Heating or Ventilating System 3	Air noise, plumbing, flushing of toilet, air-conditioning, including elevators.
h. Footfalls, Door Slams	Impacts other than from handling equipment.

The last category would obviously relate directly to the

[2]Noise categories and definitions are quoted from the report, Noise in Hospitals Located Near Freeways, page 23.

[3]By the definition of the authors this category seems to have included practically all mechanical equipment noises and was not limited to "heating or ventilating system."

floor and its covering if door slams were not included. In any case, the questionnaire summary sheets for each of the ten hospitals were examined to determine the relative importance of the "Footfall" category to the other interior noise categories.

Results of three specific questions were examined. The first question was asked of patients and is quoted, "In this question, would you please list all the noises in this hospital that you are aware of (from inside or outside sources), and rate how much each disturbs you. (By disturb we mean how much the noise interferes with your rest or sleep, or simply how much it annoys you.) Write in each specific noise where indicated, and then rate on the scale just below." The questionnaire had spaces for the identification and rating of six noises, e.g.,

Noise "A" (Write in) ______________________

Not at all Disturbing		Slightly		Moderately			Very Disturbing		
1	2	3	4	5	6	7	8	9	10

The questionnaire analysts subsequently divided the above disturbance scale into the ten equal parts indicated for numberical-weighting assignments. For our purposes, the results from the ten hospitals are combined. The total number of responding patients was 165.

The results are as follows:

Noise Category	Response	Average (Weighted Disturbance)*
Hospital Equipment	31%	52.9
Patients or Visitors	24%	64.3
Hospital Personnel	22%	49.9
Radio or TV	15%	48.8
Signaling Devices	13%	44.7
Footfalls-Door Slams	7%	39.5
Heating & Ventilating System (Mechanical Equipment)	6%	34.5
Intercom	5%	24.3

*The range of the scale is 10 to 100, "not at all disturbing" to "very disturbing" respectively.

While most patients were "aware" of the noises of "Hospital Equipment", those who listed "Patients or Visitors" were disturbed to a greater degree by their noise. Note that only 7% of the responding patients listed "Footfalls-Door Slams" and they, on the average, were disturbed "slightly" by these noises.

The results of another portion of the questionnaires presented to doctors and nurses were also examined. A two-part sequence is quoted, "Do you find any noises in this hospital annoying even though you may not think them a hindrance in your work?" An occurrence scale

of "never, sometimes, often, and very often" was presented. The second part was of interest to us and is quoted, "List below the specific noises, or noise sources, that you have had in mind while making the rating above. Place a check in front of the noise that you consider to be the worst problem." There were 124 responding doctors and 143 responding nurses for a total combined response of 267. The results are as follows:

Noise Category	Percentage of those responding who listed this noise	Percentage of those listing the noise who also checked it as the worst problem
Hospital Equipment	44	29
Hospital Personnel	39	40
Patients or Visitors	37	27
Radio or TV	21	32
Intercom	14	18
Heating & Ventilating System (Mechanical Equipment)	14	17
Signaling Devices	13	29
Footfalls-Door Slams	4	10

While the doctors and nurses agreed with the patients that "Hospital Equipment" seems to be the major source of interior noise, the staff rated "Hospital Personnel" second and the patients rated "Patients or Visitors"

in that position. The category of "Footfalls-Door Slams" was rated as least offensive in this case.

The results of the following question also asked of doctors and nurses were examined. "Please list below the sources of noise that your patients complain about. Place a check in front of the noise receiving the most complaints". There were a total of 267 responding doctors and nurses.

Noise Category	Percentage of those responding who listed this noise	Percentage check-rated as most frequent complaint
Patients or Visitors	39	39
Hospital Equipment	34	21
Hospital Personnel	27	34
Radio or TV	15	44
Heating & Ventilating System (Mechanical Equipment)	11	17
Intercom	9	17
Signaling Devices	7	33
Footfalls-Door Slams	3	0

It seems clear that the noises in the category of "Footfalls and Door Slams" were not a major problem while those noises produced by "Hospital Equipment, Patients and Visitors and Hospital Personnel" would constitute the more severe interior hospital noise problems. The information necessary to separate the number of "Door Slams" from "Footfalls" was not available and neither was that information relating to the transmission of footfall noise from one floor to the rooms below. Three of the hospitals studied were one-story buildings and the remainder were multi-story buildings.

Additional insights to the acoustical environment of hospitals were obtained from interviews with hospital administrators. They, in general, indicated that noise had not affected the gross income or the occupancy rate. To their knowledge, no hospitals have had to close because of noise and they all indicated that to their knowledge, there were no noise control standards for hospitals. One responded that "some architects have guides". Internal noises created some nuisance and had more bearing upon hospital operation than did external noise sources. Administrators of three of the studied hospitals felt that hospitals were not arranged such that certain departments or areas could be more quiet than others. Other respondents held

the opposite view: one was currently working on a "masterplan", another indicated that certain departments; e.g., surgery, obstetrics and intensive care were arranged with regard to noise. In another hospital, patients were categorized into (1) operative, (2) postoperative, (3) intensive care, (4) convalescent groups and located with regard to "quietness". Another administrator indicated that hospitals were not purposely arranged regarding noise but "it works out this way that where patients are very sick, nurses and others are more quiet". One final response regarding arrangement of hospital departments was that "efficiency comes first and should noise appear that is offensive then something is done if necessary to correct the noise".

Although gross income or operational expenses may not have been affected by noise, there are clear cases where noise has affected capital expenditures. In one hospital, the pharmacy and office space were relocated because of the noise created by people and in another, a "noisy" laboratory was relocated away from patients' rooms. Sound absorbing acoustical ceilings were applied in at least four of the hospitals. Because of intrusive exterior noises at one location, the hospital administration was planning for the installation of an air-conditioning system and double-paned windows.

The major noise sources, according to the administrators, were generally the same as those identified by hospital patients and staff. The most frequent response was "people" and of course one must identify locations, functions and activities of the people and "hardware" used in the activities before prescribing noise-control measures. Prevalent locations identified were the corridors, offices, kitchens and coffee shops. Specific noise sources were:

> metal carts, handtrucks, wheel chairs, the dropping of pans and anything metal, "metal chairs on asphalt tile flooring", metal equipment and furniture, clattering garbage cans, elevators and elevator doors, air-conditioning equipment, pumps and mechanical equipment, flushing toilets and running water, telephones ringing and telephone switchboard, radio and television sets, time clocks, and snoring and coughing.

3. The Role of Floor Coverings in the Acoustical Environment

Hospital noises, their sources and some of the subjective responses to them were examined in the preceding section. With these characterizations of the hospital acoustical environment present, it is useful to explore

how floor coverings relate to the environment either by contributing to the noise problems or by alleviating some of them. Throughout the subsequent discussion, it should be understood that floor coverings comprise only one of the components of a floor-ceiling assembly and constitute only one of the exposed surfaces of the usual six-sided room.

3.1. Surface Noise Generation

The contribution of floor coverings to the noises produced as people walk and push carts over them perhaps is the most important, the least understood and most difficult problem with which to deal. Surface noise radiation has been defined tentatively as that noise radiated from a surface into the space facing the surface resulting from dynamic contact by people and objects with the surface. A task group of Subcommittee III of the American Society for Testing and Materials Committee C-20 on Acoustical Materials recently was appointed to "investigate all surface-generated noise with the eventual aim of drafting a test method to measure this type of noise". It is clear that before floor covering specifications can be written that seek to control the generation of surface noise, a uniform method of

measurement that is meaningful and repeatable must be found. The properties of floor coverings that affect noise production and in this regard, the relationship of floor coverings to the rest of the floor-ceiling assembly, must be understood fully.

3.2. Transmission of Impact-Generated Sound Through Floor-Ceiling Assemblies

Another important role of floor coverings is the degree to which they affect the transmission of footstep and other impact-generated sounds from the room above the listener. Although the inherent properties of specific floor coverings greatly influence this type of noise production, the total noise radiated to the room below depends upon the entire floor-ceiling assembly and in many cases, upon the vertical walls in contact with that assembly, i.e., the total system. The relative merits of floor coverings, however, can be determined from measurements in which the basic floor-ceiling assembly remains constant and only the surfacing material is changed. These measurements usually are of the sound pressure levels radiated into the lower room with a repeatable source of impact excitation on the floor above. In the case of multistory-hospital construction, there appears to be a limited selection of basic constructions that are used, because of the need for fire protection.

A program of relative performance of floor coverings on these basic constructions, thus, would seem practical.

3.3. Airborne Sound Transmission

Another area of concern in multistory-hospital construction is the transmission of airborne sound through the floor-ceiling assembly. As above, the floor covering is only a component of the assembly and its sound transmission loss properties usually cannot be evaluated independently of the system. Floor coverings, in general, contribute very little to the total sound transmission loss of the assembly, that is its ability to prevent airborne sound from traveling between spaces. Certain massive floor surfacings, however, such as terrazzo and ceramic tile can produce substantial contributions in this regard, but only if the floor coverings are well bonded to the floor and all cracks are sealed.

3.4. Airborne Sound Absorption

The ability of a material to convert acoustical energy to heat energy or otherwise dissipate or remove sound power is known as sound absorption. Sound absorbent materials fundamentally reduce the noise in a given room or space and in general, do very little toward

preventing airborne sound from traveling through a wall or floor. With the exception of carpeting, floor coverings do not contribute much to the total sound absorption of the space. The sound absorptive properties of materials can be measured using several methods. There is a sound box method, ASTM RM14-1,[4] that is used primarily in research and development of ceiling tile. Another method, ASTM C384-58,[5] employs an impedance tube and is useful for screening purposes. The most relevant and reliable method of measurement is The Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms, ASTM Designation C423-66.

[4] Proposed Method for Sound Box Test of Sound Absorption Coefficients of 12-in. Square Acoustical Tiles on No. 1 Mounting, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

[5] Standard Method of Test for Impedance and Absorption of Acoustical Materials by the Tube Method, ASTM Designation: C384-58.

4. NBS Laboratory Investigations

Laboratory measurements of some of the acoustical properties of selected floor coverings were performed to provide for objective comparisons of materials and some indications of their impact on the hospital noise environment. The properties investigated were the random and normal incidence sound absorption, the impact sound insulation and the relative surface noise radiation from the floor coverings. The last investigations were addressed directly to certain particular surface noise problems in hospitals. The airborne sound transmission loss properties of floor-ceiling assemblies as affected by floor coverings were not investigated in this study. Terrazzo and ceramic floor surfacings were not considered and although vinyl-asbestos tile and cushioned-backed sheet vinyl are included in these investigations, there is an emphasis on carpeting consistent with NBS Report 9895. [1] The acoustical performance data presented here were obtained from some of the same flooring materials considered in that report.

4.1. Random Incidence Sound Absorption Coefficients

The measurements of random incidence absorption coefficients were conducted in strict accordance with the Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms, ASTM Designation C423-66. A brief summary of the test method is presented here. The method covers the measurement of the sound absorption of materials in a diffuse sound field which is defined as a region in which the average rate of flow of sound energy is equal in all directions. Measurements are made in a reverberation room that is so designed that the reverberant sound field closely approximates a diffuse sound field. Figure 1 is a photograph of the new 15,000-cubic foot reverberation chamber at the National Bureau of Standards in Gaithersburg, Maryland, in which these measurements were made. The absorption coefficients of the test specimen are determined from the change in decay rate of the test signals inside the reverberation room when the test specimen is introduced. The test signals used in these measurements were 1/1-octave bands of random "pink" noise, which is noise with a continuous frequency spectrum with equal energy per constant-percentage bandwidth. The frequency pass band of the microphone circuit was limited to a 1/3-octave

Figure 1. The National Bureau of Standards' Reverberation Chamber with Carpet Specimen in Place.

bandwidth centered at the same frequency as that of the source 1/1-octave band. The test signal is turned on long enough for the sound pressure level in the reverberation room to reach a steady state. When the signal is turned off the sound pressure level decreases, and the rate of decay is determined from measurements of the average time for the sound pressure level to decay through a certain range. The absorption of the room and its contents is calculated from the Sabine equation:

$$A = \frac{0.9210\ Vd}{c}$$

where A = sound absorption, in sabins

V = room volume, in cubic feet

d = average rate of decay, in decibels per second

c = speed of sound in air, in feet per second

The sound absorption coefficient, α, of the test specimen in sabins per square foot is given by:

$$\alpha = \frac{A_2 - A_1}{S}$$

where A_1 = sound absorption of the empty room

A_2 = sound absorption of the room with the test specimen

S = area of the specimen

In general, sound absorption will vary with frequency

and measurements are made at a series of six standard frequencies. The random incidence absorption coefficients of each of the selected floor coverings are given in Table 1. The floor coverings are given in order of increasing absorption coefficients from vinyl-asbestos tile to nylon carpeting with a foam rubber cushion backing. The vinyl-asbestos tile was glued to the reverberation room floor with a floor-tile adhesive. Unless otherwise indicated, the carpet specimens were laid directly on the reverberation room floor. The peripheral edges of the carpet specimens were taped to minimize edge effects.

The first three floor coverings given in Table 1 were investigated for static and rolling friction and resilience and the results are reported in the NBS Report 9895 [1].

Neither the vinyl-asbestos tile nor the cushioned-backed sheet vinyl possess great sound absorptive properties primarily because of their reflective surfaces. The latter covering, however, performed reasonably well in reducing impact-generated sound transmission. The nylon carpeting with a sponge-vinyl backing (C) ranked least absorptive of the carpeting specimens tested. The short pile height (0.135-in.) and the closed-cell

Table 1. Random Incidence Sound Absorption Coefficients

Floor Covering	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	NRC*
A	.01	.01	.01	.04	.04	.04	.05
B	.01	.03	.03	.03	.05	.11	.05
C	.01	.03	.07	.12	.30	.29	.15
D	.01	.05	.09	.21	.47	.64	.20
E	.01	.04	.09	.26	.58	.66	.25
F	.01	.05	.20	.48	.54	.60	.30

*Noise Reduction Coefficient (NRC) is the average of the coefficients at 250, 500, 1000, and 2000 Hz expressed to the nearest integral multiple of .05.

A. 1/8- x 9- x 9-in. vinyl-asbestos tile. (Sample area, 72 ft^2)

B. 1/16-in. vinyl sheet floor covering with 1/8-in. attached sponge vinyl cushion. (Sample area, 46 ft^2)

C. Nylon looped pile tufted carpet with attached sponge vinyl cushion. The pile height was 0.135-in., the backing 0.156-in. thick and the total weight 93 oz/yd^2.

D. Nylon looped pile tufted carpet with jute backing glued to floor with peel-up adhesive. The pile height was 0.200-in. with 8.1 stitches per inch and total weight 72 oz/yd^2. (Sample area, 72 ft^2)

E. Same carpet as above, except sample was not glued to floor.

F. Nylon looped pile tufted carpet with attached 1/8-in. foam rubber cushion. The pile height was 0.190-in. with 7.0 stitches per inch and total weight 89 oz/yd^2. (Sample area, 74 ft^2)

backing do not constitute highly efficient absorbers.

Interesting results were obtained from tests (D) and (E). The sound absorption of the same test specimen was measured under two different mounting conditions. One condition (E) was with the carpet specimen placed flatly on the floor but not adhered to it and the other (D) was with the specimen glued to the floor with a peel-up adhesive. The absorption coefficients were not affected greatly at the lower frequencies (125-500 Hz) but gluing the specimen to the floor reduced the coefficients at the higher frequencies (1000-4000 Hz). The reductions are probably attributable to less air entrapment beneath the specimen when glued and also to the fact that the glue engulfed the backing to some degree and set-up rigidly, thus exposing less of the porous, sound absorptive material.

Tests (E) and (F) were intended to show the effects of a closed-cell foam rubber self-pad versus the same carpeting with a jute-backing. The carpetings, however, were not identical in <u>all</u> respects. There were slight differences in the pile height, the number of stitches per inch, and in the yarn face weight. The differences in the absorption coefficients therefore, are not solely attributable to the difference in the backing materials.

4.2. Normal Incidence Sound Absorption Coefficients

The measurements of normal incidence absorption coefficients were conducted in strict accordance with the Standard Method of Test for Impedance and Absorption of Acoustical Materials by the Tube Method, ASTM Designation C384-58. This method of test is limited to the use of apparatus consisting of a tube of uniform cross-section and fixed length, excited by a single tone of selectable frequency, in which the standing wave pattern in front of a specimen upon which plane waves impinge at normal incidence is explored with a moving probe tube or microphone. Figure 2 illustrates the apparatus employed.

It is important to note that the most generally accepted method for determining sound absorption coefficients of materials is the reverberation chamber method described in the preceding section, 4.1. Its acceptance is based on the fact that field conditions can be closely simulated as regards the incidence of sound waves at random angles and the methods of mounting the test specimen. Its disadvantages are that it is relatively expensive and time-consuming, requires a large specimen, and involves elaborate test facilities. The tube method, however, is a comparatively simple and rapid technique requiring a specimen of only one square foot or less.

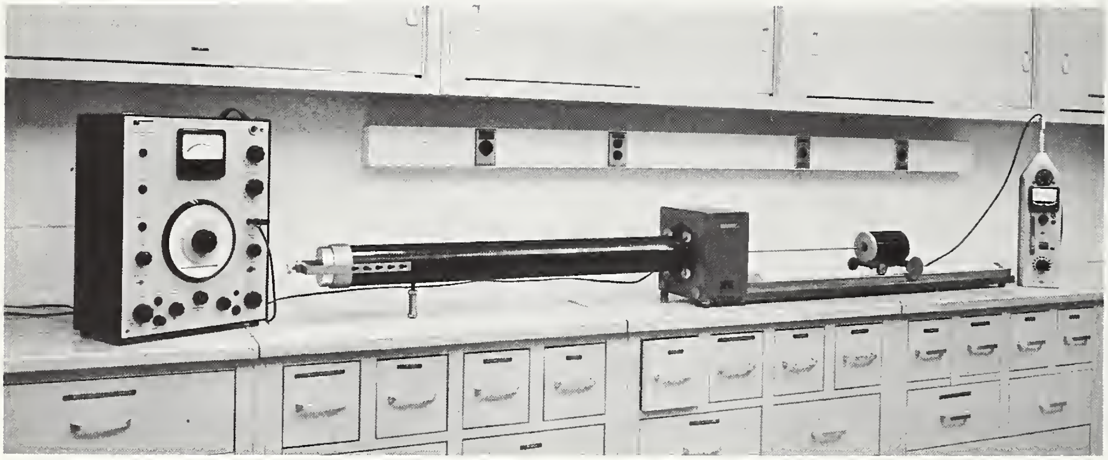


Figure 2. Standing Wave Apparatus

Normal incidence coefficients, as measured by this method, usually are lower than random incidence values and there is no unique relation between the two values. Means of estimating random incidence values from the measured normal incidence data usually involve a guess for the relation between the specific normal acoustic impedance, the angle of incidence and the sound absorption coefficient as a function of that angle. Various guesses have been made, [Refs. 4-10] with the oldest being the normal impedance assumption of Rayleigh, ca 1877, [4]. None of these assumptions, unfortunately, gives results that can be relied on for all materials. In general, these measurements are extremely useful for purposes of research and development of products as well as for preliminary screening of materials to select those that appear promising for a specific purpose. Full-scale reverberation tests are then performed.

The normal incidence absorption coefficients at six test frequencies for nineteen test specimens are given in Table 2. Three of the carpets given in Table 1, (C), (E), and (F), are also included in Table 2, (13), (8), and (12), respectively.

Table 2. Normal Incidence Sound Absorption Coefficients.

Floor Covering	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
1	--*	.05	.11	.12	.20	.65
2	.05	.06	.15	.24	.51	.74
3	--*	.04	.11	.10	.14	.35
4	--*	.04	.08	.12	.15	.46
5	--*	.04	.06	.08	.16	.36
6	.05	.06	.16	.16	.49	.74
7	--*	.04	.07	.06	.15	.42
8	--*	.04	.04	.07	.16	.54
9	.05	.07	.13	.24	.55	.57
10	.06	.07	.08	.18	.39	.67
11	.06	.06	.12	.22	.50	.75
12	.05	.05	.09	.18	.32	.72
13	--*	.04	.07	.06	.20	.32
14	--*	--*	--*	.04	.11	.05
15	--*	.03	.06	.07	.21	.48
16	--*	--*	.05	.06	.17	.27
17	--*	.03	.07	.08	.21	.44
18	--*	.04	.08	.10	.24	.50
19	.05	.09	.34	.42	.66	.53

1. Wool carpet
2. Wool carpet with attached foam rubber cushion
3. Acrylic carpet
4. Acrylic carpet
5. Carpet, 70% acrylic and 30% modacrylic
6. Carpet, 80% acrylic and 20% modacrylic, with attached foam rubber cushion
7. Nylon carpet with velvet weave
8. Nylon carpet (E in Table 1)
9. Nylon carpet, modified upholstery weave, with attached sponge rubber cushion
10. Nylon carpet with attached sponge rubber cushion
11. Nylon carpet with attached foam rubber cushion
12. Nylon carpet with attached foam rubber cushion (F in Table 1)
13. Nylon carpet with attached sponge vinyl cushion (C in Table 1)
14. Nylon carpet with solid vinyl backing
15. Polypropylene tufted carpet
16. Polypropylene felt carpet
17. Pad for carpet, 100% hair, 48 ounces per sq yd
18. Pad for carpet hair-jute sandwich, 40 ounces per sq yd
19. Wool carpet on hair-jute sandwich pad

*Absorption coefficeient below measuring capacity of apparatus.

4.3 Impact Sound Insulation

The impact sound insulation properties were measured in accordance with Field and Laboratory Measurements of Airborne and Impact Sound Transmission, ISO Recommendation R140, published by the International Organization for Standardization. Briefly, this method involves measurement of the sound pressure levels in the reverberant room below the floor-ceiling specimen while the floor surface is excited by a "standard tapping machine". Figure 3 illustrates the tapping machine employed. The sound pressure levels were measured in 1/3-octave bands and normalized to a reference room absorption of 10 m^2.

The impact sound pressure levels with four different floor coverings each on a 4-in. reinforced concrete floor slab are given in Table 3 and plotted on Graph 1. Higher sound pressure levels indicate poorer performance. The single-figure rating system, Impact Insulation Class (IIC),[6] was applied to the data and these results are also given in Table 3. This rating system was designed so that a higher IIC rating number would indicate better performance.

[6] The Insulation Class is described in Appendix A.

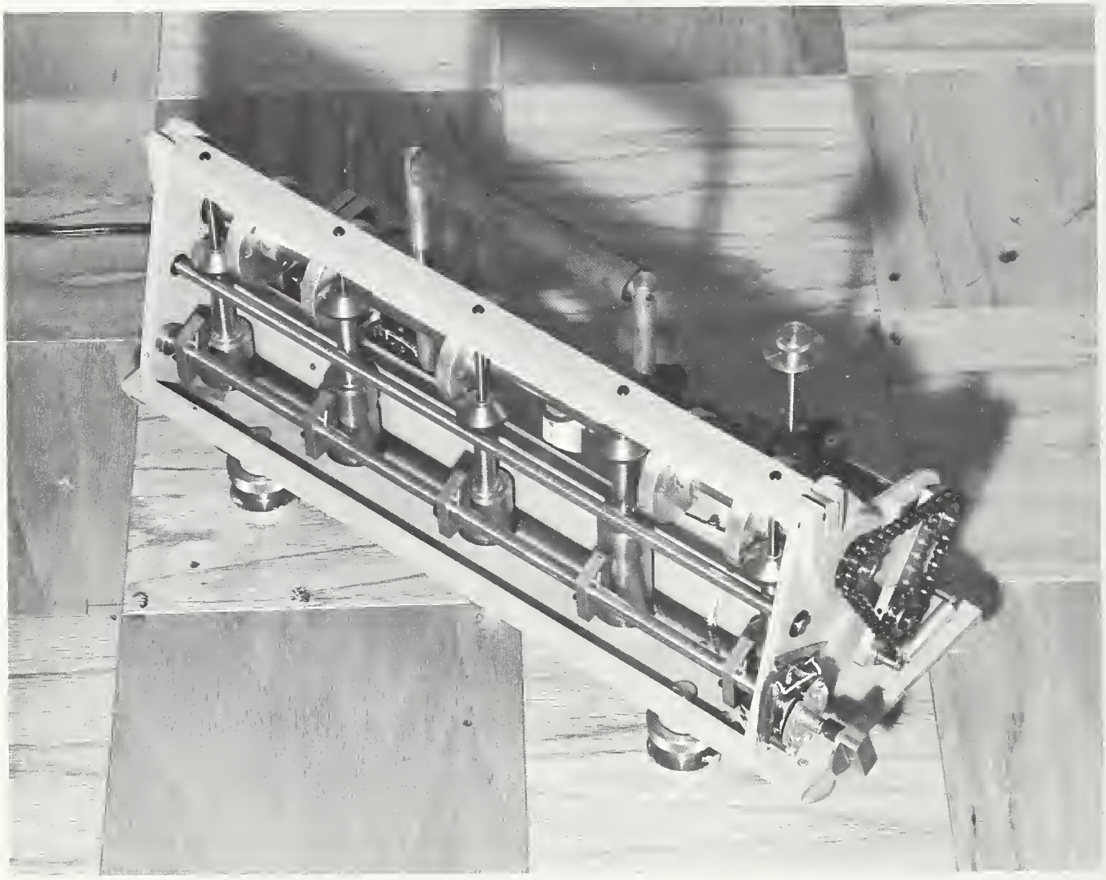


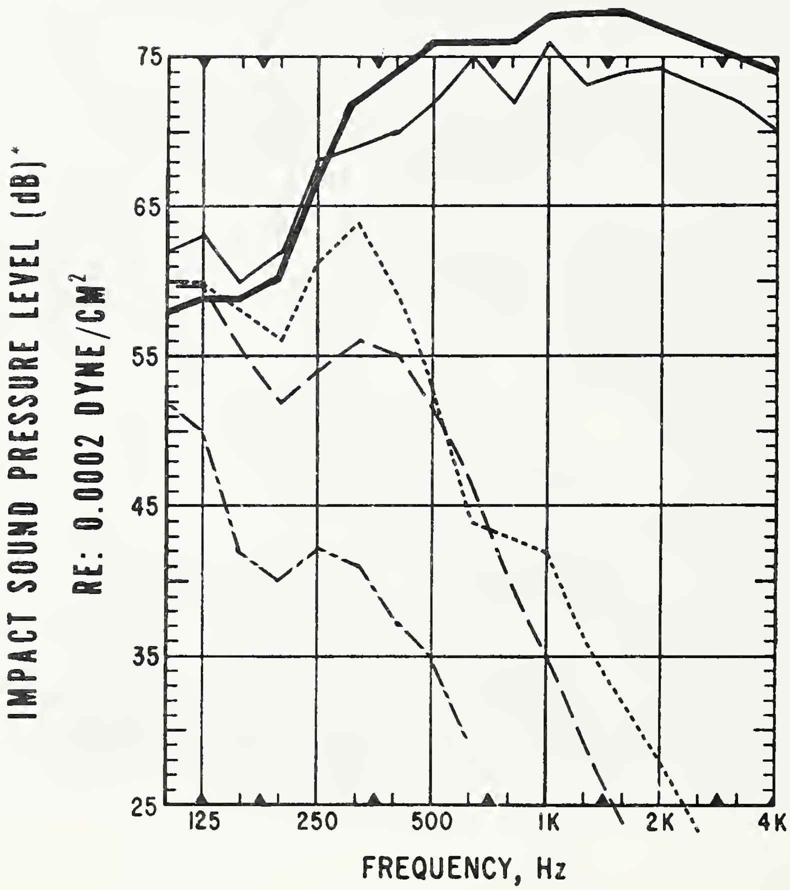
Figure 3. Tapping Machine Used in Impact Sound Insulation Measurements.

Table 3. Impact Sound Pressure Levels.

1/3-octave band Center Frequency	ISPL in dB re: $0.0002 dyne/cm^2$ Floor Covering			
(Hz)	A	B	C	D
100	62	60	60	52
125	63	60	60	50
160	60	58	55	42
200	62	56	52	40
250	68	61	54	42
315	69	64	56	41
400	70	59	55	37
500	72	53	52	35
630	75	44	48	29
800	72	43	40	20
1000	76	42	35	--*
1250	73	36	29	--
1600	74	32	24	--
2000	74	28	20	--
2500	73	23	--*	--
3150	72	--*	--	--
4000	70	--	--	--
IIC	28	56	60	68

A: 1/8- x 9- x 9-in. vinyl-asbestos tile
B: Cushioned-back sheet vinyl glued to floor
C: Nylon carpet with jute backing
D: Nylon carpet with attached foam rubber cushion
All of the above floor coverings were placed on a 4-in. reinforced concrete slab.

*Insufficient signal-to-noise ratio for accurate measurements.



*1/3-octave band data normalized to $A_o = 10m^2$

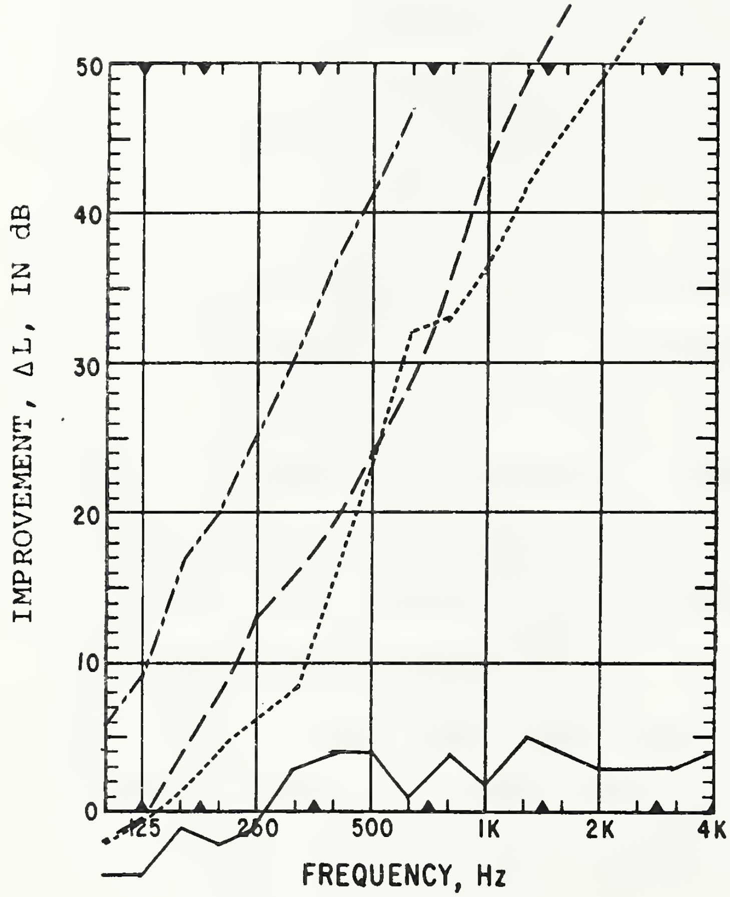
——— Slab without floor covering
——— 1/8-in. vinyl-asbestos tile, IIC = 28
·········· Cushioned-back sheet vinyl glued to floor, IIC = 56
— — — Nylon carpet with jute backing, IIC = 60
—·—·— Nylon carpet with attached foam rubber cushion, IIC = 68

Graph 1. Impact Sound Pressure Levels of 4-in. Reinforced Concrete Slab with Four Floor Coverings.

As indicated above, the performance of the floor covering in reducing impact-generated sound transmission can be determined only in relative terms by varying the floor covering and keeping everything else constant. The improvement, ΔL in dB, in sound insulation as a function of floor covering relative to the bare 4-in.-thick reinforced concrete slab is plotted on Graph 2. The degree of improvement of each floor covering will, of course, be different when placed upon other floor-ceiling assemblies. This is especially true with the lightweight joist constructions.

Although standard methods of measurement in the control of impact sound transmission have existed in some European countries for fifteen years or more [12], the progress in this area in the United States has been slow. There have been objections to the above procedure, the main objection being that the tapping machine does not produce impacts that resemble closely those of footsteps [13]. A number of factors precluded the study of floor covering properties under real footstep excitation in the measurement program reported here; however, earlier work at NBS and by others has been performed using footstep excitation [14-22].

While the problem of impact sound transmission is among the more serious ones in multifamily-residential



1/3-octave band data

——— 1/8-in. vinyl-asbestos tile
········ Cushioned-backed sheet vinyl glued to floor
— — — Nylon carpet with jute backing
-·-·-·- Nylon carpet with attached foam rubber cushion

Graph 2. Impact Sound Insulation Improvement, Δ L in decibels, due to Application of Different Floor Coverings on a 4-in. Concrete Slab.

and office buildings, it apparently is not as severe in multistory-hospital structures. The transmission of footstep-generated noise from one floor to the one beneath was not among the major hospital noise problems identified. The noise produced by footsteps in the corridors, however, and not transmitted to the space below, but radiated into patients' rooms is a serious problem. This "surface noise radiation" is discussed below.

4.4. Surface Noise Radiation Reduction

While the noise produced by people and objects in dynamic contact with floor surfacings is highly objectionable, especially in hospitals, there unfortunately is no standard method for its measurement and characterization at this time (An ASTM Committee Task Group presently has an assignment in this area.)

Our background investigations of hospital noise sources very clearly indicated that several types of rolling "carts" and the like produced annoyance among patients and staff. A survey of such objects was made at the Clinical Center of the National Institutes of Health and four of the "worst offenders" were selected for measurement purposes in this program.

The typical food tray cart is shown in Figure 4. Figure 5 illustrates the general purpose cart and Figures 6 and 7 show the 20 gallon trash can on a dolly and the soiled-linen hamper frame, respectively.

Each of these devices was pushed about by the same individual in the same manner on each of two floor coverings placed on the reverberation chamber floor. The selected floor coverings were the 1/8-in. vinyl-asbestos tile glued with a tile mastic and the nylon carpeting with jute backing adhered to the floor with a peel-up adhesive. The sound pressure levels were measured at four microphone positions in the reverberation chamber and analyzed in 1/1-octave frequency bands. The results were averaged and normalized to a reference room sound absorption of 10 square meters. The comparative results are plotted on Graphs 3-6. Mr. C. D. Strong of NIH modified a trash-can-and-dolly assembly with some rubber pads. Comparative measurements were made and the results are plotted on Graph 3. In all cases, the carts and devices were empty.

In the absence of a standardized method of test, it was felt that the above described measurements which utilized real sources of hospital noise on two diverse floor coverings in a laboratory with known acoustical characteristics would yield useful information. It

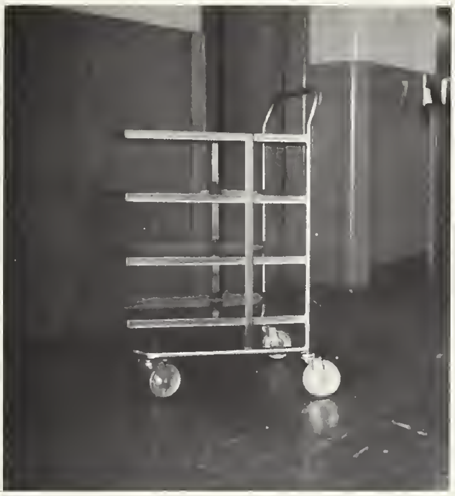
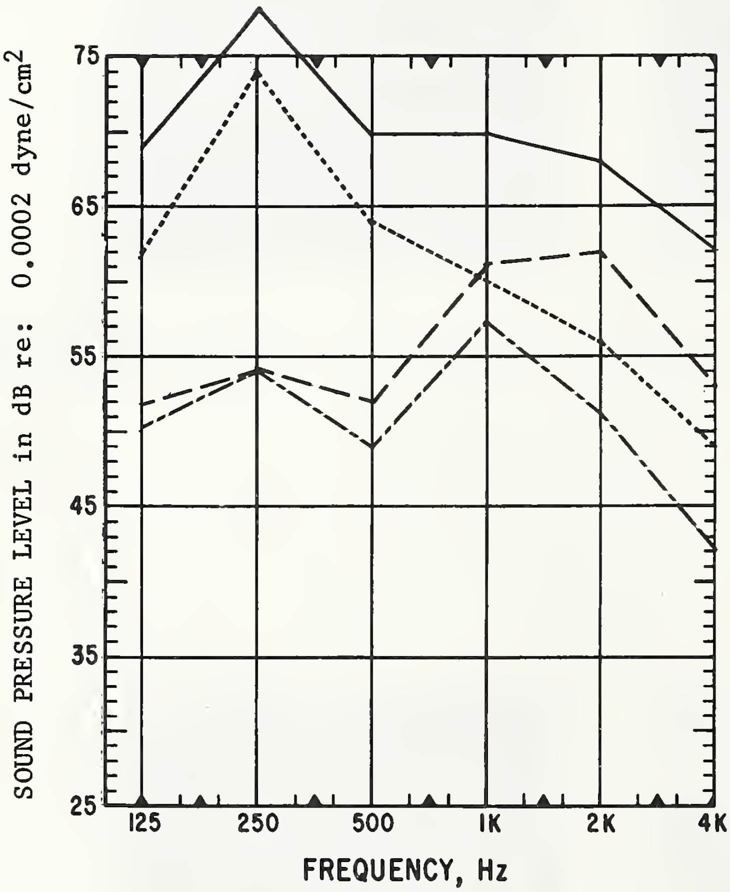


Figure 4. Food Tray Cart.

Figure 5. General Purpose Cart.

Figure 6. 20-Gallon Trash Can on Dolly.

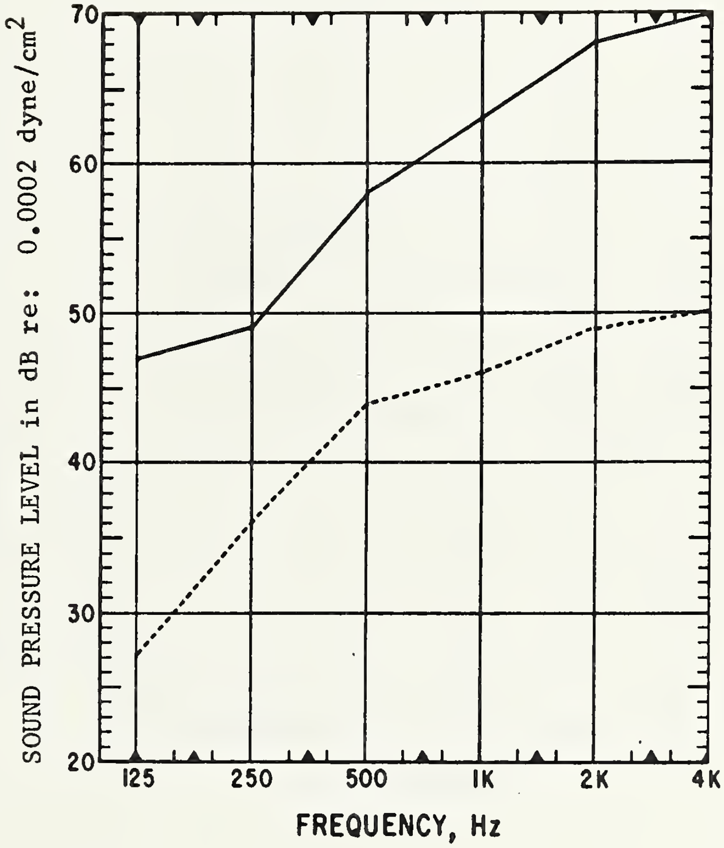
Figure 7. Soiled-Linen Hamper Frame.



Trash Can and Dolly without rubber cushions under trash can
——— On Tile ------ On Carpet

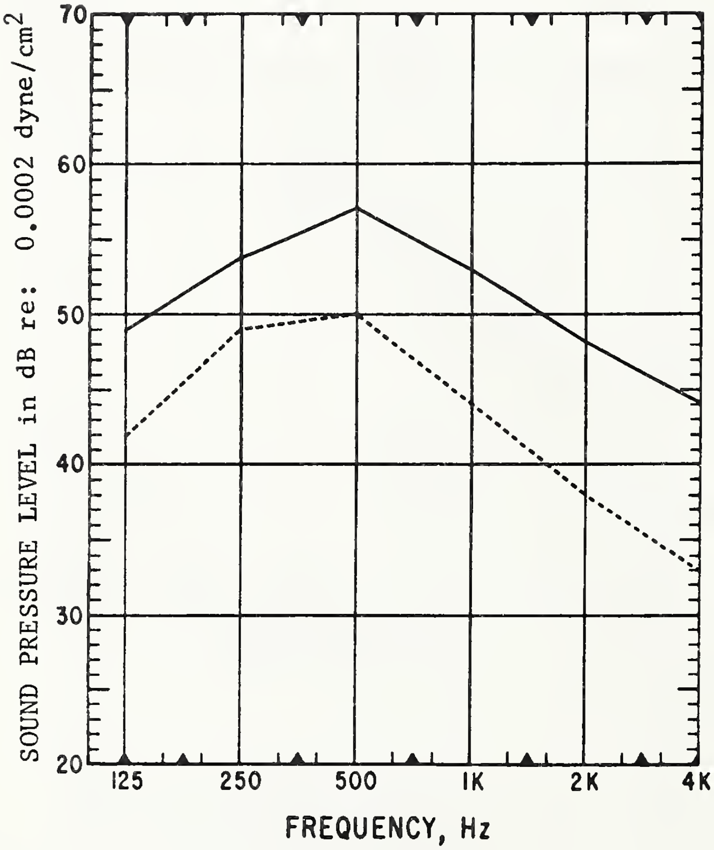
Trash Can and Dolly with rubber cushions under trash can
— — — On Tile -·-·- On Carpet

Graph 3. Surface Noise Generation.



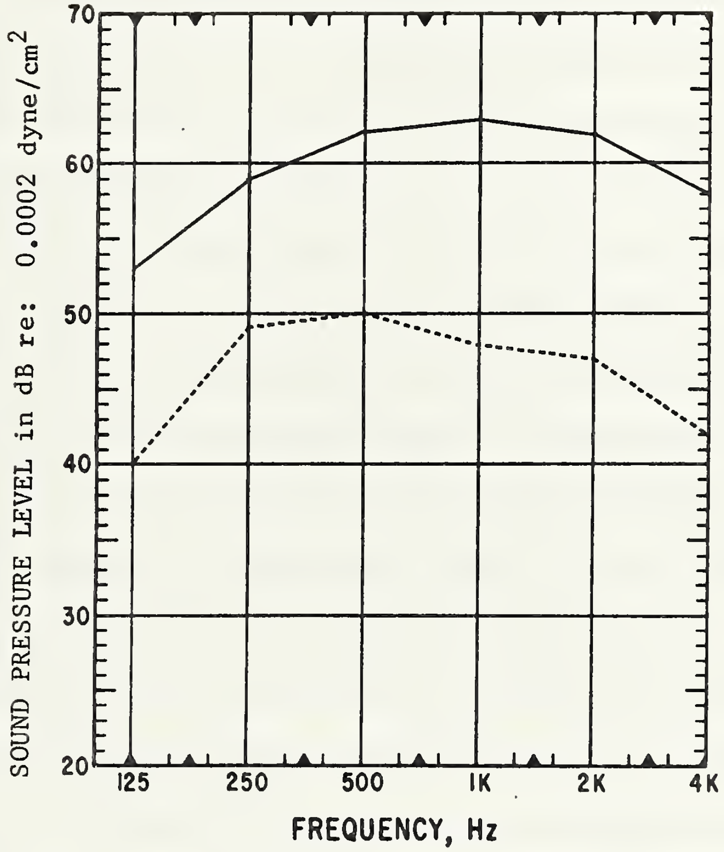
Soiled-Linen Hamper Frame
———— On Tile
-------- On Carpet

Graph 4. Surface Noise Generation.



Food Tray Cart
——— On Tile
--------- On Carpet

Graph 5. Surface Noise Generation.



General Purpose Cart
——— On Tile
--------- On Carpet

Graph 6. Surface Noise Generation.

is in the area of surface noise reduction that carpeting might have its greatest acoustical potential.

5. Development of Acoustical Performance Criteria

The ultimate objective of performance specifications is the satisfaction of the consumers which in this case would be the hospital patients, staff, administrators and owners. The satisfaction is derived from the control of noise and the creation of a pleasant, comfortable acoustical environment. Before meaningful acoustical performance specifications can be written, however, the criteria of acceptability or annoyance should be established. In addition, standard methods of measurement for objective determinations of performance are necessary. It is clear that all of these ingredients are not presently available in the case of hospital floor coverings. The following discussions, therefore, are indications of the probable performance based upon present information.

In the total hospital acoustical environment, it should be recalled that the role of the floor covering is not necessarily the most dominant.

5.1. Airborne Sound Absorption

Very little, if any, sound absorption can be anticipated from floor coverings other than carpeting. Although many carpet floor coverings possess relatively high sound absorptive properties especially in conjunction with certain underlayments, there are strong indications that carpetings that might be suitable for hospital usage are not nearly as absorptive as those used in residential applications.

The low pile height and "tightness of the weave" that appear to be necessary to the ease of movement of carts and the like are not conducive to high-valued sound absorption coefficients. The difficulties encountered with pads and underlayments, vis-a-vis the rubber pads with regard to fire protection and the hair-felt pads related to bacteriological considerations, force us to discount consideration of the sound absorptive properties of such pads. Impermeability of the backing appears to be necessary to prevent the retention of liquids and therefore the sound absorptive properties of the backing material cannot be included.

Noise Reduction Coefficients (NRC) values of 0.15 to 0.35 appear to be realistically obtainable for hospital carpetings. Generally speaking, these values imply that 15 to 35 per cent of the sound energy incident on the carpeting would be absorbed or otherwise dissipated. The recommended method of measurement is the Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms, ASTM Designation C423-66 of the American Society for Testing and Materials.

5.2 Impact Sound Transmission

The transmission of impact-generated sounds depends not only on the floor covering but also on the rest of the structure, as discussed previously. In the future, it might be useful to express the improvements achieved by various floor coverings on a fundamental floor ceiling construction typically found in hospitals. The form could be a single-figure-of-merit as determined under specific types of impact excitation relevant to hospitals. At the present time however, our best recommendation for a criterion is the Impact Insulation Class (IIC) with a value of 50 or greater. The measurements are of the total floor-ceiling assembly, not just the covering, and utilize the tapping machine specified

in Field and Laboratory Measurements of Airborne and Impact Sound Transmission, ISO R140-1960(E), published by the International Organization for Standardization. The resultant sound pressure levels are to be normalized to a reference 10-square-meter sound absorption and the single-figure rating assigned according to Appendix A. The controversial issues alluded to in Section 4.3 are not being ignored. Alternate methods of measurement however, are not developed sufficiently at this time to form the basis for any other recommendations for use as criteria.

5.3. Surface Noise Reduction

In the area of surface noise reduction where floor coverings can potentially be very effective noise control materials, there is insufficient information to recommend any performance criteria. There are clear "common-sense" indications, supported by our measurements, that carpeting can be quite effective in reducing contact noises. Resiliently backed vinyl coverings may also be very effective. The greatest noise production would be from ceramic tile, terrazzo and similar floor surfacing materials.

6. Proposals for Future Work

6.1. Field Study of Hospital Environment

It is proposed that a study of the noise environment in an active hospital be conducted. The study would involve objective measurements of the noises produced in a given nursing unit by routine activities. The total acoustical environment would be characterized over a statistically-valid period of time. A floor covering would then be installed and objective acoustical measurements would be repeated. The net effect upon the total environment, due to the installation of a specific floor covering thus could be determined. Laboratory measurements of the acoustical properties also would be conducted on specimens of the same material. Correlation of field and laboratory results would then be possible.

During the course of this project, plans were in progress to conduct this type of study at the Clinical Center of the National Institutes of Health. Close working relationships were established with personnel there before certain circumstances precluded the conduct of the study. With the Clinical Center being a research hospital,

there are unique features that enhance an acoustical study there.

6.2. Laboratory Studies of Surface Noise Radiation

An extensive study of physical properties, sources of excitation, and radiation patterns is necessary to the development of criteria and methods of measurement.

6.3. Impact Sound Insulation

In addition to surface noise generation, it is necessary to further investigate impact sound transmission with regard to sources of excitation and methods of measurement.

6.4. Subjective Response to Acoustical Environments

Common to all acoustical studies is the matter of subjective response to changes in the acoustical environment. It is proposed that a study of the responses of patients, staff and administrators be conducted in conjunction with objective measurements in a field hospital.

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Appendix A

Classification of Floor-Ceiling Assemblies for General Impact Noise Control Purposes

A1. Introduction

A1.1 In choosing the proper floor-ceiling assembly to meet the impact sound insulation requirements of a particular building installation, it is recommended that the entire impact sound pressure level curve of the structure be studied, rather than simply choosing the assembly solely on the basis of its single-figure rating. Indeed, experience has clearly shown that no single-figure rating can properly evaluate the acoustical merits of a floor structure unless it takes into account the variation of impact sound transmission with frequency. For such reasons, a certain amount of discretion must be exercised in the use of a single-figure rating, especially for performance criteria purposes. Nevertheless, it is commonly acknowledged that a single-figure rating is useful for categorizing floor structures with respect to their sound insulating properties. With some reservations, such ratings can be used by architects, builders and specification or code authorities to establish acoustical criteria for buildings.

A2. Scope

The purpose of this classification is to provide a single-figure rating, which permits the comparison of the impact sound insulating merits of floor-ceiling assemblies in terms of a reference contour. The rating is called the IMPACT INSULATION CLASS, IIC.

This classification is applicable only to impact test data based on 1/3-octave band measurements in the frequency range 100-3150 Hz. Use of this classification for the purpose of comparing or rating test data based on octave band measurements may cause confusion and result in erroneous or misleading evaluations.

A3. Significance

The IIC system rates floor-ceiling structures in <u>ascending degrees of impact sound insulation</u>, without any arbitrarily chosen reference or zero level. Thus, IIC values increasing in magnitude indicate a correspondingly increasing degree of impact sound insulation. This avoids the confusing practice of dealing with "negative sound insulation values", which arise from the use of a zero-valued reference contour. The IIC rating system contains the inherent versatility which allows code

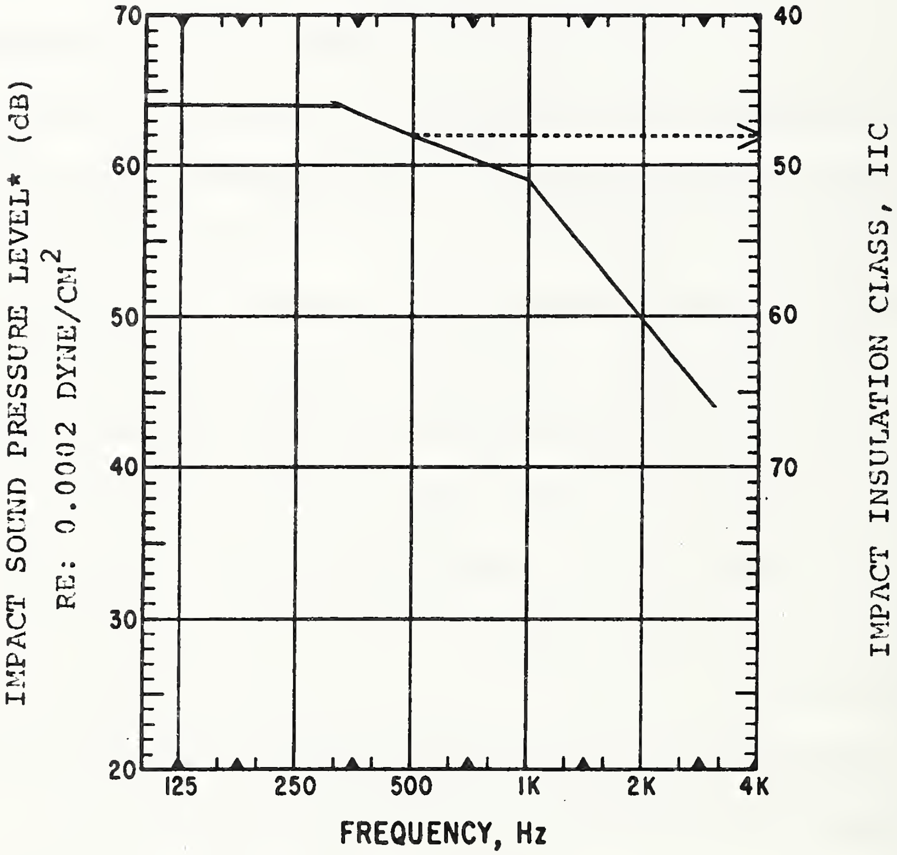
authorities to establish and revise their own criteria, if necessary, without the awesome task of re-evaluating structures tested previously.

A4. Summary of Method

A4.1 To determine the Impact Insulation Class of a floor-ceiling assembly, its normalized impact sound pressure levels in the 16 test frequency bands are compared with those of the IIC reference contour, having the form illustrated in Fig. A1.

A4.2 The IIC reference contour may be constructed as follows: a horizontal line-segment in the interval 100 to 315 Hz; a middle line-segment decreasing 5 dB in the interval 315 to 1000 Hz; followed by a high frequency line-segment decreasing 15 dB in the interval 1000 to 3150 Hz.

A4.3 For purposes of conformity and facilitating comparison of results, it is required that the reference contour, normalized impact test data, and both the impact sound pressure level scale (left ordinate) and the "Impact Insulation Class" scale (right ordinate) be plotted on a graphical form with an ordinate scale of 2 mm per decibel and an abscissa scale of 50 mm per frequency decade, (i.e. 5 cm grid; where 25 dB = frequency decade)



*1/3-OCTAVE BAND DATA NORMALIZED TO $A_o = 10m^2$

Figure A1. Typical IIC Contour (IIC = 52).

as shown in Fig. A1.

The relationship between the left and right ordinate scales is shown in Fig. A1, i.e., the sum of the left and right ordinate values has been arbitrarily chosen to be 110.

A5. Graphical Determination of Impact Insulation Class, IIC

When the impact sound pressure levels for the test specimen are plotted graphically in accordance with A4.3 and Fig. A1, the IMPACT INSULATION CLASS may be determined by comparison with a transparent overlay on which the IIC reference contour is drawn. The IIC contour is shifted vertically relative to the test curve until some of the measured ISPL values for the test specimen fall above those of the IIC contour and the following conditions are fulfilled: (1) the sum of the excesses (i.e., the deviations above the contour) shall not be greater than 32 dB; (2) the maximum excess at a single test point shall not exceed 8 dB. When the contour is adjusted to the maximum value (in integral decibels) that meets the above requirements, the IMPACT INSULATION CLASS for the specimen is the value on the intersection of the contour and the 500-Hz-ordinate.

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